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REVIEW

Nordic walking influence on biomechanical parameters: a systematic review

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ABSTRACT

INTRODUCTION: Nordic walking (NW) as a form of physical activity has been shown to have benefits in various domains, but little is known about the effect of NW on more specific biomechanical parameters. The purpose is to determine the impact of NW on the following parameters: walking speed/distance, muscle activation, spatiotemporal parameters, kinematics and ground reaction force.
EVIDENCE ACQUISITION: A literature search was carried out in different databases from October 2008 to October 2018. This review was conducted and reported in accordance with the PRISMA statement. Finally, 42 studies with a median PEDro Score of 5.5/10 were included.
EVIDENCE SYNTHESIS: The included studies reported increased walking distance (+14.8%, P<0.05), walking speed (+25.5%, P<0.05), and stride length (+10.4%, P<0.05), but decreased cadence (-6.2%, P<0.05). NW generally increased: muscle activation and strength for upper limbs; upper and lower limb range of motion, and ground reaction force.
CONCLUSIONS: NW has beneficial effects on many biomechanical parameters. It appears to be an effective way of doing physical activity and could be used in physical rehabilitation or in daily life.

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KEY WORDS: Exercise; Gait; Locomotion.

Walking plays a primary role in daily life, combining automatic and voluntary activities. Walking involves different human body systems, such as the nervous, osteoarticular and muscular systems. Walking is a succession of unipodal and bipodal supports with a crossing between scapular and pelvic girdles that helps biped balance and reduces energy consumption.[1] The coordinated movement between the upper and lower limbs is partly ruled by the central pattern generators located in the spinal cord.[2] They are an assemblage of interneurons that generate information independently from the brain and enable muscular synergy leading to a motorcycle when walking. However, certain diseases affecting the nervous system (*e.g.*, Parkinson's disease [PD], parkinsonian syndromes, brain injury) or accidents (*e.g.*, spinal cord injury, head trauma) may result in reduced walking ability and upper-lower limb coordination issues,[3] both leading to limitations in the activities of daily life.

Nordic walking (NW) has emerged as a new physical activity in recent years. This physical activity was initially developed by Finnish cross-country skiers in the aim of preserving their physical fitness during the summer.[4] NW is similar to natural walking, the major difference is the addition of active use of a pair of NW poles and the correct use of the poles makes it possible to engage the upper body more during the act of walking[5] (see Figure 1, for more detailed information about NW, consult the link of the previous reference). This type of walking is now used by a large public. Besides being very easy to learn,[6] recent studies among healthy adults have shown benefits in vari-

Figure 1.—Nordic walking picture.

ous domains; including walking,[7] cardio-vascular,[8] metabolic,[9] and psychological wellness,[10] overall activation of the musculature of the limbs and trunk[11, 12] as well as pain relief.[13, 14] In addition to being practiced by healthy persons, NW is often used with the elderly[15] as an aerobic activity to prevent the complications of a sedentary life. NW has also been used for several rehabilitation programs in PD,[16] musculoskeletal diseases (*i.e.* osteoarthritis)[17, 18] or cardiovascular disease.[8] No study has identified any major risk associated with practicing NW.

A previous systematic review by Tschentscher *et al.*[19] described NW in terms of its general benefits (*e.g.*, exercise capacity, walking distance and energy expenditure). However, more specific biomechanical parameters, unevaluated in this review, (*e.g.*, upper and lower limb kinematics; electromyography [EMG], or ground reaction force [GRF]) could provide new insights into the utility of NW in physical rehabilitation, especially in nervous system diseases.

Therefore, the purpose of this systematic review was to determine the impact of NW in both healthy and diseased populations, in terms of general and specific biomechanical parameters, such as walking speed/distance, muscle activation, spatiotemporal variables, kinematics and GRF. This review considers both healthy people and people with disease.

Evidence acquisition

This systematic review of the literature was conducted and reported in accordance with the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) statement.[20]

Data sources and searches

The following databases were searched for relevant studies: Medline (Pubmed), Cochrane (Cochrane library) and the Physiotherapy Evidence Database (PEDro), from October 2008 until October 2018. In order to identify relevant articles, the following keywords and operators were used: *"nordic walking" OR "pole walking" OR "walking poles" OR "nordic pole walking" OR "hiking poles" OR "nordic pole" AND "gait" OR "walking" OR "functional performance" OR "pattern" OR "motion capture" OR "kinematic" OR "kinetic" OR "dynamic analysis" OR "muscle activation" OR "muscle synergies" OR "performance analysis" OR "posture" OR "trunk".*

The search was conducted with Medical Subject Heading (MeSH) terms and non-MeSH terms (in *italics*), as several terms associated with NW were not present in the MeSH list.

Study selection

For completeness, all articles with at least one keyword referring to NW in the title were included in this phase. Duplicate articles from the different databases were excluded.

Based on the titles and abstracts, the eligibility criteria for study selection were: studies that referred to at least one variable from a biomechanical analysis of NW (*e.g.*, spatiotemporal parameters, kinematics); and articles comparing NW with other techniques and/or groups (*e.g.*, conventional walking, other exercise practices, inter- and intra-individuals). Exclusion criteria were studies not in the English language; studies not including comparative statistical analysis; dissertations, systematic reviews, guidelines, congress abstracts, editorials, letters, books and comments.

Afterwards, the above-mentioned eligibility criteria were applied to the full texts. Finally, the references of each article selected for inclusion were manually checked to ensure that no relevant publications were overlooked.

Data extraction and quality assessment

Articles were selected and read by two reviewers (M.R. and Y.S.). Disagreements between reviewers were resolved by discussion to obtain consensus. If no consensus was reached, a third reviewer (P.D.) was consulted.

In order to assess the methodological quality of the studies, articles were Scored with the PEDro Scale[21] comprising 11 items. If the PEDro Score already existed in its database, it was also reported. This scale is used to assess external (criterion 1), internal validity (criteria 2 to 9) and interpretability of the findings (criteria 10 and 11) of clinical trials or group comparison studies.[22] Only criteria 2 to 11 were considered for the final Score in line with the recommendations for use of the scale.

Data synthesis and analysis

Reviewers recorded the follow characteristics for each publication included: type of study, participant characteristics (number, gender, age), participant inclusion/exclusion criteria, study protocol (task, session (number and duration), frequency, intensity), means of evaluation, assessment criteria and PEDro Score. In this review, we considered our PEDro Score (Supplementary Digital Material 1: Supplementary Table I).[6, 7, 11-15, 17, 23-56] The results of this review were expressed with the mean (SD) values of all variables studied, the comparisons with the P values and the changes were expressed in percentage for between groups and/or pre/postprogram comparisons.

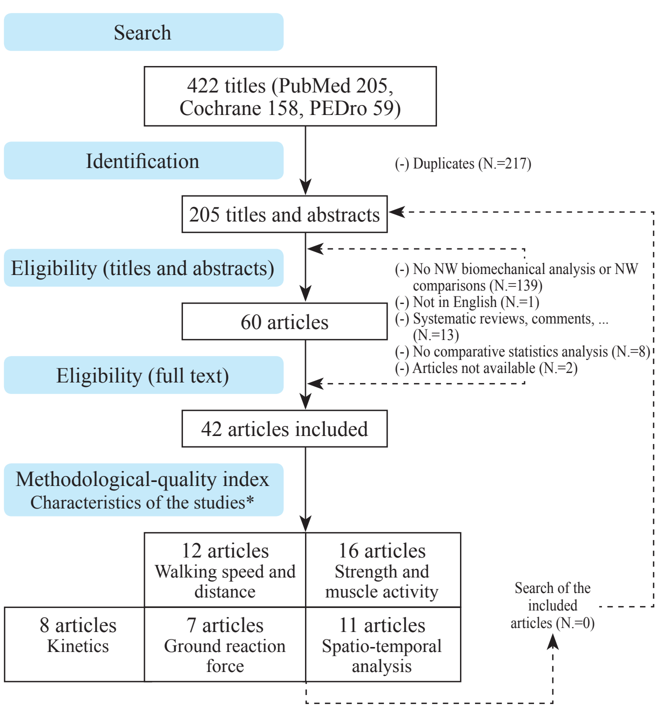

Figure 2.—Flowchart.
*12 articles carried out more than 1 biomechanical approach; these results were indcluded in their respective groups.

Evidence synthesis

Selection of articles

Figure 2 shows the selection process for the articles included in this review. Using the chosen search terms, a total of 422 articles were identified from the 3 databases. Finally, 42 studies[6, 7, 11-15, 17, 23-56] meeting all the inclusion criteria were included in the review.

Regarding the methodological quality index (Supplementary Table I), the mean PEDro Score was 5.5/10 points. The lowest Score was 3/10[35, 47, 56] and the highest Score was 8/10.[27] Two items, concerning therapist and subject blinding, were not rated for any study. The following 2 criteria were respected for more than 90% of the studies: baseline intergroup similarity and >85% follow-up, and the intergroup statistical comparison criterion was met by all the studies included in the review.

Characteristics of the studies

In terms of the study design, 22 studies were randomized control trials, 1 pseudo-randomized control trial and 19 non-randomized controlled trials. Considering the limited number of studies, all were analyzed, regardless of their design and methodological quality index. Therefore, the results showed below should be considered carefully.

Regarding the participants' characteristics, (Supplementary Digital Material 2: Supplementary Table II)[6, 7, 11-15, 17, 23-56] most studies (N.=26, 62%) included healthy participants. Seven studies evaluated patients with PD, 1 investigated patients with fibromyalgia, 6 investigated patients with cardiovascular disease and 2 investigated patients with osteoarthritis. The average (SD) number of participants was 36.1 (30.3) with a mean age of 50.3 (18.7) years. Overall, 55.1% of all participants were men, 44.9% were women. The most recurrent inclusion/non-inclusion criteria of the chosen studies were that participants should be able to walk without any walking aid and that they did not have any neuromuscular or musculoskeletal issues that could impair NW and other walking activities. However, 19 studies did not specify any exclusion criteria. For the studies including patients, the criteria were disease specific. For the studies that included patients with PD: 5 studies used the Hoehn & Yahr classification (*i.e.*, studies included patients from stage I to stage II) and 2 used the United Kingdom Parkinson's Disease Society Brain Bank Clinical Diagnostic criteria.[48] The study about fibromyalgia[26] included patients based on the American College of Rheumatology 1990 criteria.[57] Cardiovascular studies had more specific inclusion criteria for each disease studied (*i.e.*, chronic obstructive pulmonary disease, heart failure). For the osteoarthritis studies, the inclusion criteria were a confirmed diagnostic of osteoarthritis of the hip[18] or the knee,[17] respectively based on clinical hip osteoarthritis according to the American College of Rheumatology criteria or on confirmed knee osteoarthritis by radiography.

Protocols

From the 42 articles, 20 were a single-day evaluation. However, some studies included a previsit to record participants' socio-demographic and anthropometric characteristics, or to explain the study procedures, or to explain the NW technique before the day of evaluation. For the other studies, the mean duration of the NW training was 11 weeks (range; 4-36 weeks). These studies include a pre- and a postevaluation, *i.e.* before and after the training program. Only two studies included evaluations during the program[14, 31] and only 1 study[42] included a long-term follow-up (10 months after the end of the program). On average, 3 NW sessions per week were carried out (range; 2-5 sessions) and each session lasted 61 minutes (range; 30–75 minutes). Four studies[28, 31, 35, 42] did not indicate the session duration and 1 study[42] did not specify the number of sessions per week.

Outcomes

The biomechanical approaches chosen to investigate the effect of NW were classified in 5 main categories (Figure 2, Supplementary Table II): 12 articles studied walking speed and distance, 16 studied strength and muscle activation; 11 studied spatiotemporal variables; 8 studied kinematics and 7 studied GRF and plantar pressure. Twelve articles used more than one biomechanical approach; these results were included in their respective groups (Supplementary Digital Material 3: Supplementary Table III).[6, 7, 11-15, 17, 23-56]

Walking distance and speed (12 studies totaling 624 participants)

Most of the studies (9 out of 10) considered walking distance based on the analysis of the 6-minute walk test or the 12-minute walk test. They justified their choice by the ease of these tests for the assessment of functional walking capacity. Only 1 study considered the maximum walking distance as a primary outcome.[13] Together, these studies found that the NW group increased their distance, and the average percentage improvement was 14.8% (8.0%) for the NW group. The greatest improvement was observed in the study by Keast *et al.* in patients with heart failure.[32]

Comparing NW *versus* conventional walking (CW), 3 studies found that results for NW groups were significantly better, and 3 found that results were numerically but not statistically significantly better. Comparing NW *versus* sedentary controls (SC) and general exercise groups, the results were significantly improved in the NW group.

Two studies compared the walking speed, namely self-selected walking speed[23, 28] (NW *vs*. CW) and found that the NW groups walked faster than CW groups by 24.5(18.2)%. Bang *et al.*[27] used the 10-meter walk test and reported that the NW group had a greater improvement than the CW group among a PD population (improvement of 9.6% in the NW group).

Some studies included patients with peripheral artery disease[13, 56] and intermittent claudication, while claudication distance was considered in two studies. NW compared to CW improved the claudication distance on average by 53.0 (17.0)%.

Muscle activation (8 studies totaling 127 participants) and strength (7 studies totaling 313 participants)

Eight studies analyzed muscle activity with surface EMG. This analysis was conducted on muscles of the lower limbs,[11, 33, 37, 40] upper limbs[11, 33, 36, 38, 40] and trunk.[12, 58] For the lower limbs, generally no significant difference was found between NW and CW groups. Nevertheless, 2 studies observed decreased activation for the following muscles: biceps femoralis, gluteus lateralis, vastus medialis, rectus femoris in one study;[40] and biceps femoralis, vastus lateralis, gastrocnemius and the tibialis anterior in the other.[37]

Regarding upper limb EMG in the NW group, all studies observed increased activation for the following muscles: biceps brachii, triceps brachii and deltoid (anterior and posterior). Three studies[11, 33, 38] found increased activation of the latissimus dorsi and two found increased activation of the trapezius.[36, 38] Schiffer *et al.*[36] studied the upper limb EMG when adding weights on the poles. The only difference found was increased biceps brachii activation when adding 1.5kg compared to no added weight.

For the trunk EMG, two studies[12, 58] reported increased activation of the external oblique and rectus abdominis in the NW group. In particular, the study by Zoffoli *et al.*[12] specified that this higher activation only occurred with an increased treadmill slope. The same study[12] reported increased activation of the rectus spinae at 100% of the preferred transition speed.

Eight studies,[15, 24, 25, 32, 34, 35, 39, 42] considered strength either with functional tests, such as the arm curl and chair stand (*i.e.*, these 2 tests were extracted from the Senior Fitness Test[59]) or with quantitative strength, assessed with a dynamometer or by manual testing (*e.g.*, grip strength,[60] elbow flexion). For lower limb strength results, 5 studies found a significant improvement in the NW group and 4 studies found an improvement when comparing NW with another group(s) (1 *versus* CW, 1 *versus* SC, and 2 *versus* general exercise), while 1 study did not find any difference. Generally, NW increased upper limb strength in 6 out of 7 studies. One study compared NW *versus* general exercise[35] and found better results on the arm curl test in the general exercise group than in the NW group with healthy older adults.

Spatiotemporal parameters (11 studies totaling 336 participants)

Studies considering the spatiotemporal analysis took several variables into account, among which the two most widely used were cadence (steps/minute or in Hertz) and stride or step length (meters). Other studies considered time variables (seconds) such as stride time, step time, single support time and double support time.

Most of the studies found that NW increased stride length (7 studies out of 8) and decreased cadence (4 studies out of 6). NW, for the within group comparison and compared with CW, increased stride length respectively by 10.4% and 6.1 (1.8)% while NW, for the within group comparison and compared with CW, decreased cadence respectively by 6.2 (3.0)% and 8.9 (5.2)%.

For time variables,[7, 44, 46, 50] NW increased single support time (+ 9.7 (6.4)%), double support time (+ 21.4%) and the total support time (+ 21.4 (17.1)%) compared to CW.

However, two studies found different results: one,[7] comparing NW *versus* CW in healthy young adults (mean age 23 years), reported the opposite of the above-mentioned studies. They indicated an increase of 14.2% in cadence and decreased step and stride (respectively -13.6% and -13%). Another study[48] comparing NW between PD patients and heathy older adults, found a decreased cadence in the PD group (- 8.9%), but an increased cadence in the healthy older adults group (+ 1.7%).

Kinematics (8 studies totaling 143 participants)

Kinematic analyses were performed for the upper limbs,[17, 45] trunk and pelvis[14, 17, 45, 47, 51] and lower limbs.[6, 44, 52] The range of motion (ROM) was expressed in degrees or millimeters. All studies compared NW *versus* CW. Studies found that upper limb ROM increased in the NW groups (arm: + 23.4% and forearm: + 422.2%).[17, 45] For the trunk, results were not consistent. One study found no difference for trunk ROM;[45] one found a decrease in the sagittal plane;[47] and another found a decreased ROM in the frontal plane.[51] Regarding pelvis ROM, one study[14] found an increase in pelvic tilt (+ 23.3%) and pelvic torsion (+ 233.3%). For the lower limbs, one study found an increase in maximum hip flexion[52] whereas another study found no difference.[6] For the knee ROM, an increase was found in the sagittal and transverse planes.[52] For the ankle, an increased value for the maximum pronation was found[44, 52] (+15.4 (6.5)%).

Ground reaction force (5 studies totaling 99 participants) and plantar pressure (2 studies totaling 62 participants)

NW increased GRF, except for the vertical force at take-off/push-off (-5.4 (4.0)%) in three studies.[23, 44, 53] Park *et al.*[7] found that the GRF during mid-stance phase decreased by 10.9%, but only when the preferred speed during NW was higher. Regarding plantar pressure, two studies[54, 55] found that NW decreased pressure at the metatarsal heads by 42.6%. One study[54] found decreased plantar pressure at the hallux (-64.6%).

Discussion

NW could be used as non-supervised intervention to improve patients' walking capacity. In this regard, previous studies have shown the utility of NW, but only using general outcomes. Therefore, the aim of this systematic review was to evaluate the impacts of NW in terms of more specific variables. In the present review, NW was studied and classified according to 5 main biomechanical approaches: walking speed and distance; muscle activation and strength; spatiotemporal parameters; kinematics; and GRF. Forty-two articles were included in this review, of which 22 were randomized control trials, 1 pseudo-randomized control trial and 19 non-randomized controlled trials.

It is important to note that given the few studies identified in the literature, all of them were taken into account for analysis in this systematic review, regardless of their quality. Furthermore, although the PEDro Score was assessed, it was not considered for analysis of the studies. The average PEDro Score was 5.5; which corresponds to *fair* quality.[61] Consequently, the results presented in this review should be interpreted with caution.

Regarding participants' characteristics, the studies included different participant profiles. Besides healthy persons, the most frequent disease contexts were PD, pulmonary and cardiovascular disease, osteoarthritis and fibromyalgia. The participants included also had different levels of physical activity (*i.e.*, sedentary, athletic), varying ages (*i.e.*, groups from 21.4 years[33] to 75.2 years[35]) and various degrees of experience with NW; some studies considered NW instructors,[11, 23, 36, 38, 45, 52] whereas others studies considered novices to NW (*i.e.*, with only a few hours spent learning the technique). Collectively, these results suggest that NW could be practiced by a wide range of participants.

Since some participants were new to NW (with only a few hours spent learning the technique) whereas others had had weeks of practice or were NW instructors, this might explain the wide range of results observed.

Walking distance and speed

Considering all studies and statistically significant differences, NW groups increased their walking distance by 14.8%. For the studies comparing NW to CW, the improvement in walking distance was 10.1%. NW also increased walking speed by 25.5% for all the studies comparing NW to CW.

In the literature, in patients with PD, different active treatments have been tested to improve walking. A study using treadmill training (3 times per week, for 4 weeks) found an increase in the distance on the 6MWT of 11.7%,[62] while another study observed an increase of 16.7% in distance after 10 weeks of dance therapy.[63] A study of dopaminergic medication found an increase in walking speed of 8.3% in PD patients with the medication, as compared to those without.[64] Compared to these results, NW could be used as a simple alternative to improve walking distance and speed, on top of other treatments to prevent gait impairment in patients with PD.[65] Other populations, such as the elderly, might also yield a benefit from NW, since walking speed tends to decrease with progression of age or disease stage.[66]

Muscle activation and strength

Muscle activation and strength differences were mostly found for the upper limbs. Both were increased when NW was compared to CW. For the lower limbs, muscle activation did not differ between NW and CW, but on the functional strength tests, NW showed better results than CW. Regarding the trunk muscles, the studies showed increased activity of the external oblique and rectus abdominis in 2 studies.[12, 58] Taken together, NW as compared with CW seems to be a form of exercise that increases upper limb and trunk muscle activity and strength. These improvements could be useful for activities of daily living that solicit the upper limbs, such as bathing, carrying things or preparing food.[67]

By simultaneously soliciting several muscles, NW could also help prevent sarcopenia due to aging. Indeed, muscle mass has been shown to decrease annually by 1.5% from the age of 50 to 60 years old (participants mean age: 50.3 (18.7) years old) and by 3% after 60 years of age.[68] The same could be observed in PD, where severity of sarcopenia was linked to disease severity.[69] In such cases, NW could be a form of physical activity that is effective in increasing muscle activity and strength.

Spatiotemporal analysis

While improving gait speed, NW groups appeared to give precedence to stride length (+10.4%), instead of increasing cadence (- 6.2%). The decline in walking speed with aging starts by a decrease in step length rather than by a decrease in cadence.[65] This is also observed in other populations, such as patients with PD[70] or patients with multiple sclerosis (MS),[71] in whom the main strategy to prevent gait speed reduction is to increase cadence. Moreover, by emphasizing increased step length, NW could preserve the necessary ROM for walking, thus delaying or avoiding the need for patients to adopt a new walking strategy.

Compared with other studies, in multicenter programs of physical therapy for patients with MS, a 5.1% increase in stride length at normal speed[72] was found, and physical therapy for patients with PD also found an increase in stride length of 2.4% after 12 weeks of a combination of various activities (*e.g.*, walking, dancing, or stretching).[73] The improvements observed in the studies of NW were all numerically greater.

Kinematics

NW generally increased upper and lower limb ROM. Increased upper limb ROM could be useful in some neurological pathologies, such as PD. Indeed, in these diseases, arm swing and interlimb coordination are reduced.[74] For the trunk movements, results were conflicting: 1 study found no difference in trunk ROM,[45] 1 observed a decrease in the sagittal plane,[47] while another found a decrease in the frontal plane.[51] Regarding pelvic movement, one study found increased pelvic tilt and pelvic torsion when comparing NW to CW. Since NW solicits both the upper and lower limbs, we expected to find some studies examining the coordination between limbs. However, we did not identify any study that investigated this parameter. Although some studies analyzed pelvic ROM, the results were conflicting, and the number of participants small. Further studies are warranted to explore interlimb coordination in NW.

GRF and plantar pressure

In persons practicing NW, there was an observed increase in the values of GRF in all axes, except for vertical force at push-off[23, 44] (-5.4%). The decreased values at push-off might be explained by the fact that, at push-off, forces are also distributed on the lower limbs and on the poles. Regarding the increased GRF, several explanations may be proposed. In 3 out of 5 studies,[7, 23, 53] speed was not controlled, and increased vertical GRF was observed compared to CW. For the 2 studies that controlled the speed, 1 found a significant decrease in GRF at push-off,[44] whereas the other did not.[52] Further investigations might be needed to ascertain whether the increased GRF was due to the speed[75] or to the NW *per se*.

Limitations of the study

This review considered all studies reporting investigations of NW in terms of overall and specific biomechanical evaluations. The main limitation of this study was that, for the purposes of exhaustiveness, all studies that met the inclusion criterion were taken into account, regardless of their quality or size. On average, the studies included had a *fair* quality index based on the PEDro Score (*i.e.*, 5.5).

Perspectives

In view of the growing interest in this form of walking, the increasing number of people doing NW,[76] and its potential to improve physical activity, this systematic review should be updated in the future.

Conclusions

In light of this analysis, NW appears to be an effective way of doing physical activity with positive effects on walking distance and speed, muscle activation, spatiotemporal parameters, kinematics and GRF. NW appears to be an attractive form of exercise for unsupervised physical rehabilitation in different populations. However, in view of the small number of studies, their quality, and the growing number of people doing NW, further studies should be performed to confirm the results observed in this systematic review.

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